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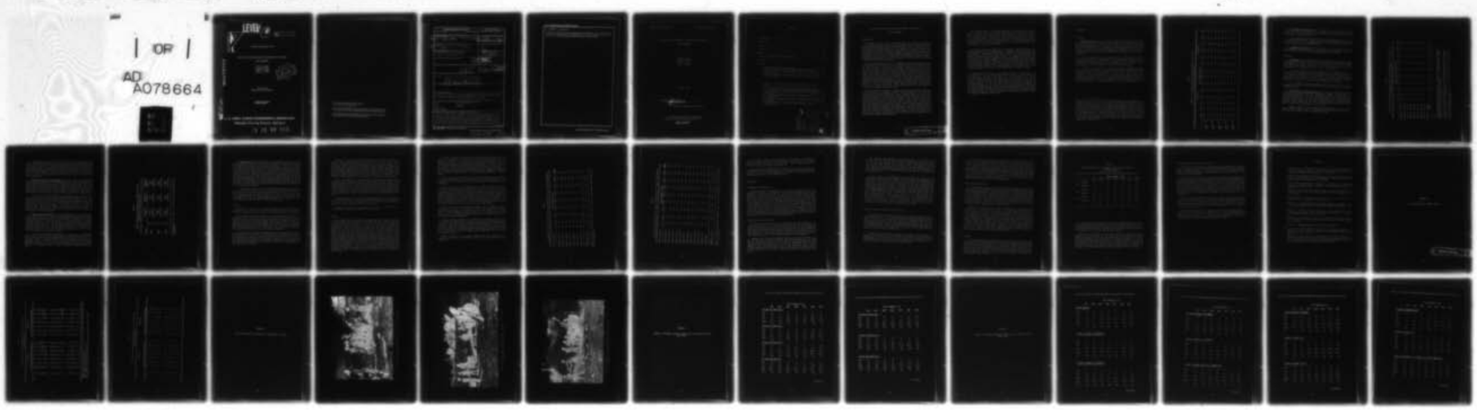

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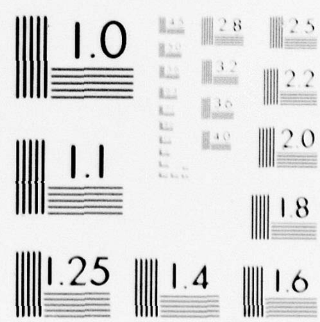

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EFFECTS OF ARTILLERY NOISE ON THE HEARING OF PROTECTED CREW PERSONNEL

David C. Hodge
G. Richard Price
Nancy L. Dukes
Samuel J. Murff

October 1979
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U. S. ARMY HUMAN ENGINEERING LABORATORY

Aberdeen Proving Ground, Maryland

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A test was conducted to determine loading rates for three artillery systems, and both male and female crews participated. Audiometric and acoustical support were provided to assess the crews' noise exposure, look for trends in the threshold shift data, and compare the threshold shifts with that permitted under present damage risk criteria. The impulse noise exposures were quite variable, due to crew mobility and low zone charges. There were no instances of excessive threshold shift, and only a few

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instances of threshold shift approaching the allowable limits. There were no obvious trends across test conditions. The main auditory goal of the test, viz., to avoid excessive hearing losses, was achieved.

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CONTENTS

EFFECTS OF ARTILLERY NOISE ON THE HEARING OF PROTECTED

CREW PERSONNEL

INTRODUCTION

The hazards to hearing from intense impulse noise exposure are a matter of considerable concern for the US Army. Impulse noise exposure causes temporary and permanent hearing losses which may result in premature loss of the skills of trained soldiers (11). Damage risk criteria have been developed for the aural effects of impulse noise exposure (2,3,9), and incorporated into materiel design standards (5). Recently there has been a resurgence of interest in impulse noise hazards, including possible nonauditory effects of blast overpressure, and systematic research aimed at developing long-range solutions to impulse noise problems are being conducted by several Army agencies (7).

Despite the existence of two fundamentally different damage risk criteria (DRC) for the aural effects of impulse noise, there have been very few investigations of the effects of artillery noise on hearing. For the most part, impulse noise studies have been conducted with other noise sources (e.g., small arms), and the DRC curve(s) have been extrapolated to higher sound pressure levels or longer durations. Until recently that was judged an acceptable practice, but now the existing DRC are being called into question because of the possibility that the resulting design standards may have overestimated the hazard from gunfire impulses with peak energies at low spectral frequencies. Also, with the improvements that have taken place in impulse noise measuring instrumentation over the past decade, it is now a relatively simple matter to measure the spectral content of an impulse, and there is hope that new DRC can be developed on the basis of spectral information (10).

Unprotected human exposure to impulse noise in experiments where the human participant is the direct object of the investigation have not been conducted by the US Army since 1970, and it seems unlikely that this type of experimentation will be resumed in the near future. Nor has there been any recent testing involving protected impulse noise exposures in which the human participants were the direct object. Army acousticians have, therefore, been constantly on the alert for any weapon tests in which the human participants are the indirect object and which might yield worthwhile data if pre- and post-exposure audiometry, etc., were conducted. Such a test was conducted at Aberdeen Proving Ground, Maryland, during May and June 1978. This test permitted the gathering of data on the effects of repeated artillery noise exposure on the hearing of protected gun crews, both male and female, including one test condition which approached the exposure limits of MIL-STD-1474A(MI).

The Artillery Team of the Systems Performance and Concepts Directorate, USAHEL, conducted this field study to determine the effects of projectile weight on artillery rates of fire (8). Three different artillery systems were loaded and fired in the process, and audiometric support was provided to the Artillery Team to insure that the crew personnel did not sustain excessive hearing losses. This audiometric testing was essentially "piggy-backed" on the primary purposes for the test, and played little part in defining the test plan or scenario.

There were two major phases to the artillery loading study, with somewhat different overall objectives. In Phase I there were three gun crews made up of male enlisted personnel, all of whom possessed MOS 13B (artilleryman). These crews loaded and fired 105, 122, and 155mm artillery systems to establish maximum rates of fire. For Phase 2 there were two crews made up of volunteer female enlisted personnel who first participated in extensive and intensive physical conditioning and training. These female personnel loaded and fired the 105 and 155mm artillery systems to determine whether female personnel could sustain the minimum rates of fire required by these systems. All crew personnel in both phases wore single hearing protection (ear plugs) at all times during the weapon firing.

There were three auditory or acoustical aspects to the study. (a) There have been very few instrumented artillery firings in which crews have been exposed to impulse noise daily for a week or more; so it was of interest to observe whether there might be any systematic trends in the temporary hearing loss data. (b) One of the test conditions (i.e., the 122mm gun system) reached the approximate exposure limits imposed by MIL-STD-1474A(MI) (5); in that case it was of interest to compare the resulting temporary hearing losses with that permitted under the standard. (c) Finally, there had been no previous artillery firing tests with female gun crews (at least in the US), so it was of interest to compare hearing thresholds for male and female soldiers and the resulting threshold shifts for comparable exposure conditions.

METHODOLOGY

Gun Crews

1. Qualifications. There were five gun crews: three male (A, B and C) and two female (D and E). Crews A and B consisted of nine enlisted males each from the 82d Airborne Division, Fort Bragg, NC. Seventeen of these 18 men had been assigned Class H1 profiles for hearing; one had been assigned a Class H2 profile.[1] All were experienced artillerymen with 13B MOS's. The hearing levels of crews A and B are summarized in Table 1. The pre-exposure baseline hearing levels for the individual crew members are given in Appendix A.

Crew C consisted of nine enlisted men from the Materiel Test Directorate Detachment at Aberdeen Proving Ground, MD. They, too, were experienced artillerymen with 13B MOS's, and all had been assigned Class H1 profiles for hearing. (See Table 1 for a summary of their hearing levels, and Appendix A for each individual's baseline hearing levels.)

Crews D and E consisted of six and seven female enlisted personnel, respectively, from various commands and agencies at Aberdeen Proving Ground, MD. None of these personnel had 13B MOS's, and most were from relatively sedentary assignments. For that reason the females were volunteers, and they participated in a three-week training and physical conditioning regimen prior to the loading and firing tests. All of the female crew personnel had been assigned Class H1 profiles for hearing; their hearing levels are likewise summarized in Table 1 and Appendix A.

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[1]Class H1 profile is defined as ANSI-1969 hearing level in each ear not more than 29 dB at 500 Hz, 25 dB at 1000 Hz, 23.5 dB at 2000 Hz, or 46 dB at 4000 Hz. (These values were obtained by correcting the values given in Appendix VIII of AR 40-501 (4) to ANSI-1969 audiometer zero.) Class H2 profile is defined as ANSI-1969 hearing level in both ears not more than 34 dB at 500 Hz, 30 dB at 1000 Hz, 28.5 dB at 2000 Hz, or 56 dB at 4000 Hz; or, the better ear not to exceed 29 dB at 500 Hz, 25 dB at 1000 Hz, 23.5 dB at 2000 Hz or 36 dB at 4000 Hz, in which case the worse ear is not evaluated and may, in fact, be totally deaf. (It should be noted, however, that a person totally deaf in one ear would not ordinarily be assigned to a combat arm of the service.)

TABLE 1

Summary of the Hearing Levels of the Five Artillery Firing Crews
(dB re ANSI-1969 Audiometer Zero)

		LEFT EAR							RIGHT EAR						
		Test Frequencies (Hz)													
		500	1K	2K	3K	4K	6K	8K	500	1K	2K	3K	4K	6K	8K
Crew A (M) N=9	$\bar{X}$	10.6	6.3	4.7	7.7	13.1	19.7	14.2	8.7	4.2	1.4	6.9	6.0	15.1	9.2
	σ	5.3	4.7	7.3	19.5	24.0	29.5	21.9	4.8	5.8	5.7	13.7	10.8	25.0	19.1
Crew B (M) N=9	$\bar{X}$	8.3	3.0	5.3	4.7	8.7	10.4	9.2	5.3	1.8	2.0	1.9	5.0	11.4	10.0
	σ	4.2	5.0	7.3	4.9	6.3	9.4	13.9	4.6	7.5	10.2	9.5	6.8	18.0	19.2
Crew C (M) N=9	$\bar{X}$	11.4	7.6	7.7	12.0	20.4	15.9	5.7	7.9	5.4	5.4	11.3	12.9	12.9	12.2
	σ	2.5	6.5	8.0	24.0	27.9	23.0	6.1	4.8	4.4	10.4	25.0	26.6	20.7	18.9
Crew D (F) N=6	$\bar{X}$	6.0	2.7	0.2	4.3	5.8	6.5	4.3	3.2	-2.8	-2.7	2.5	2.5	3.7	8.7
	σ	4.9	3.5	4.7	5.4	3.9	6.2	5.5	3.7	3.9	1.2	3.3	4.7	8.3	11.4
Crew E (F) N=7	$\bar{X}$	6.7	1.9	1.7	0.7	1.7	3.7	4.7	2.9	3.4	3.0	0.4	1.0	2.3	1.3
	σ	5.6	4.7	5.3	4.7	3.7	5.3	4.0	3.9	4.3	4.8	4.6	5.2	7.3	5.4

2. Otological examinations. Prior to the first live firing, the crew members had their ears examined by a physician to insure that their ear canals were clean and healthy and that their ear drums were intact. Ear canals were cleaned as required.

Crew members were also fitted with, and instructed in the use of, the appropriate size triple flange earplug. Two crew members, one male and one female, could not be accommodated with the triple flange plugs, and instead, used the foam E-A-R® earplugs.

3. Audiometric training. Prior to the first live firing, all of the crew personnel were trained on the audiometric test procedure. Three or more complete testing cycles were administered to each person.

Equipment

1. Audiometers. Three TRACOR ARJ-4C and one TRACOR RA-206 audiometers were utilized in supporting the artillery loading study. The ARJ-4C's were programmed to test seven frequencies in each ear (0.5, 1, 2, 3, 4, 6 and 8 kHz). The RA-206 audiometer was used in its "screening" mode, which was programmed for six frequencies (0.5, 1, 2, 3, 4 and 6 kHz).

Two of the ARJ-4C's had been modified to test a HTL range of -30 to 70 dB, while the remaining ARJ-4C was unmodified and provided the usual -10 to 90 dB range. The RA-206 had a switchable 30 dB pad, so it could be used with either of two ranges, 0-100 dB or -30 to 70 dB HTL. Crew personnel were more or less "matched" with the audiometers on the basis of pre-test audiometric baselines to provide the most complete data possible.

All threshold testing was conducted with pulsing tones. All four audiometers employed TDH-39 earphones which were mounted in standard MX-41AR cushions.

2. Audiometric testing facility. The artillery loading study was conducted at the Plate Range (Building M680) at Aberdeen Proving Ground. At the range, audiometric testing was administered inside a semi-trailer van that had been modified to provide a relatively quiet test environment. An anteroom provided space for the four audiometers, etc., while the main interior room contained four individual testing booths. One of these booths had been locally fabricated; the other three were Eckel model AB 200 HD Type 1 booths that were purchased for this study.

Table 2 shows the octave band SPL's measured inside the four test booths, with and without the air conditioning in operation, along with the ANSI maximum allowable levels for audiometer rooms.

TABLE 2

Octave Band Sound Pressure Levels (dB) In Four Test Booths With and Without the Air Conditioner Operated On Low Setting

	Band Center Frequency (Hz)									
	31	63	125	250	500	1K	2K	4K	8K	16K
Booth #1 - A/C On	52	49	46	32	33	18	13	15	17	19
Booth #1 - A/C Off	52	48	44	32	35	14	13	15	17	19
Booth #2 - A/C On	53	58	48	40	29	16	10	8	7	8
Booth #2 - A/C Off	53	58	47	38	29	12	8	8	8	8
Booth #3 - A/C On	57	51	48	37	23	11	12	11	11	11
Booth #3 - A/C Off	53	46	49	36	22	13	10	11	10	10
Booth #4 - A/C On	56	55	46	35	26	15	14	15	14	18
Booth #4 - A/C Off	51	46	44	34	23	14	15	14	15	18
ANSI S3.1 - Maximum Levels	—	—	34.5	23.0	21.5	29.5	34.5	42.0	45.0	—

Notes:

1. By observing the octave band analyzer, it seemed that the 500 Hz band contained the compressor noise. There was an audible pulsation that corresponded to meter needle fluctuations only when measuring SPL in that band.

2. Contrary to subjective impressions, Booth #2 (locally fabricated) had the lowest background noise levels of the four except at 500 Hz where Booth #3 was the lowest.

3. Booth #1, which was fartherest from the air conditioner, had the highest noise levels in the 500-8000 Hz range.

During Phase I of the test (May 1978), the air conditioning was turned off whenever audiometric tests were actually being administered. During Phase 2 (June 1978), however, higher outdoor ambient temperatures were experienced. This necessitated leaving the air conditioning on continuously and, as indicated by Table 2 and Appendix A, some minor masking problems probably occurred, particularly at 500 Hz. An empirical test for masking suggested a maximum of about 5 dB at any test frequency. Also, of course, the masking was in effect for both the pre- and post-firing tests.

3. Artillery systems and ammunition. All of the crews, male and female, participated in portions of the loading study in which standard Army type-classified howitzers were fired. These howitzers consisted of the 105mm, M101A1, and the 155mm M114A1. Standard inert projectiles, with inert fuses, were fired from these systems. In addition, crews A and B loaded and fired a Soviet 122mm howitzer system, which was included in the study to provide rate of fire data for a system larger than 105mm but smaller than 155mm. Again, inert projectiles and fuses were used with the 122mm system.

For the 105 and 155mm systems, the propellant charge was Zone 3 and the crew area impulse noise exposure conditions were estimated to be well within the limits for personnel wearing single hearing protection. For the 122mm system, however, only top zone charges were available. These were reduced to a propellant weight of two pounds to arrive at a tradeoff between using a large enough charge to avoid having a projectile stick in the tube, and a small enough charge that the allowable daily number of rounds would be around 60-the sample size already selected for loading and firing the 105 and 155mm systems.

4. Impulse noise measurements. It was impossible to place a transducer in the actual crew area, as the mounting stand would have interfered with weapon loading operations. There was neither time nor ammunition available to correlate impulse noise data for the crew area with that of a remote measurement location outside the crew area. So it was decided to position a transducer near (i.e., just forward of) the crew area, on the assumptiom that this would provide at least an approximation of the impulse noise conditions in the crew area. The transducer location for each weapon is listed in Appendix B. The impulse noise characteristics of the three artillery systems are summarized in Table 3.

For the impulse noise measurements, the output of a Susquehanna model ST-2 pressure transducer was recorded on a Honeywell model 5600 FM tape recorder set for 40 kHz bandwidth. The tapes were played back in the laboratory using a Honeywell model 7600 tape transport set for 40 kHz bandwidth, and the recordings were analyzed with the aid of a Nicolet Explorer III transient recorder. A Hewlett-Packard computer was used to find the A- and B-duration for each shot, as defined in MIL-STD-1474A(MI) (5).

TABLE 3

Impulse Noise Characteristics of Artillery Systems
Employed In the Loading Study

System		Peak Level (dB)	A-Duration (msec)	B-Duration (msec)
	$\bar{\bar{X}}$	171.79	0.75	23.60
105mm	σ	1.23	0.07	1.63
	R	168.6-174.8	0.62-0.98	14.84-36.70
	$\bar{\bar{X}}$	172.93	1.21	34.64
155mm	σ	1.48	0.41	3.87
	R	167.7-182.5	0.85-2.20	27.60-43.60
	$\bar{\bar{X}}$	176.47	1.91	19.60
122mm	σ	0.91	0.16	2.00
	R	174.3-177.8	1.50-2.36	15.42-37.96

Left hand gage, No. 1482, in all cases. For gage location, see Appendix B.

5. <u>Hearing protective devices</u>. During the planning of this field study, it was realized that the test condition involving the 122mm howitzer system would probably constitute a "test" of the provisions of MIL-STD-1474A(MI) with respect to allowable daily impulse noise exposure. That is, the number of rounds loaded and fired from the 122mm system would roughly equal that permitted by the standard when the crew personnel are wearing single hearing protection. Comparing the distribution of temporary hearing loss resulting from the 122mm test condition(s) with that permitted by the DRC underlying the standard (CHABA) might therefore suggest whether the DRC and the design standard were valid for artillery noise exposure and single protected crew personnel. The triple flange earplug was selected for use in this test for that reason: it provides approximately the same degree of protection as other standard earplugs that were in use when the provisions of the standard were adopted.

Stated another way, the newer foam E-A-R® earplug was <u>not</u> selected for use in the test because it is generally believed to provide more protection than the devices upon which the standard is based. Use of the E-A-R® earplugs would thus have resulted in less actual noise exposure than that permissible under the present standard. However, as noted above, two crew members did use the E-A-R® earplugs because of their inability to get an acceptable fit and seal with the triple flange plugs.

Scenario

Photographs of the site are included in Appendix B. Further details of the Phase 1 test, relating to the primary objectives of the artillery loading rate program, will be found in a report by Paragallo and Dousa (8).

Crew personnel were given pre-exposure audiograms in groups of four or less. Upon arrival at the audiometric testing van, each crew member was assigned to one of the four test booths; they were instructed to return to that same booth after the weapon loading and firing was completed. The crew members' hearing levels were determined in both ears; these pre-exposure audiograms were recorded on the cards in black ink. Retesting of individual test frequencies was conducted as required to insure that the pre-exposure hearing level determinations were as reliable as possible.

As each group of crew members completed their pre-exposure audiogram, they exited their testing booths and then stopped in the anteroom to insert their earplugs. A pink noise source was turned on to a high level, and the crew members were instructed to insert their earplugs and to adjust them until the perceived noise level was minimized. Then the crew personnel left the testing van and walked to the artillery firing site to participate in the scheduled test condition.

"Murphy" was right--the test procedure rarely ran as smoothly as indicated here. Many uncontrolled and uncontrollable delays took place: delivery of ammunition, equipment malfunctions, etc. As a result, there often was a delay of half an hour between the pre-exposure audiogram and the actual start of the weapon loading and firing. Under those conditions, the inevitable happened--the crew members removed their earplugs. Then they reinserted them at the gun site on the instruction of the range safety officer. This probably means that the degree of hearing protection actually afforded the gun crews in these tests was very similar to that which they would experience in a "real world" artillery firing situation.

At the conclusion of each scheduled test condition, the crew personnel returned to the audiometric van in the same groups as before firing, so the same audiometers could be used for the post-exposure test. It was impossible to start all of the post-exposure audiograms at the same point after exposure, if for no other reason than that only four crew members could be tested at one time. All post-exposure testing was accomplished in a time window from 2 to 20 minutes after exposure. The audiometric data were not corrected to account for differences in post-exposure measurement time.

Whenever conducted, the post-exposure audiograms were recorded in red ink on the same record card as used for the pre-exposure test to simplify scoring the data. Again, individual test frequencies were retested as required to insure maximum reliability of the data.

At the conclusion of the post-exposure testing for one crew, the cycle was repeated as required to complete a day's testing.

RESULTS

The original plan was to administer audiograms only to "up to four crew members deemed to be receiving the worst noise exposure." This was changed for several reasons. After Phase 1 started, one of the ARJ-4C audiometers suffered a mechanical failure, leaving us with three functioning audiometers. Since two successive runs were then required to test four crew members (i.e., 3+1=4), we decided to test up to six crew members. Also, there was a great deal of unanticipated mobility within the experienced artillery crews; the only crew position whose incumbent did not change within and between loading conditions was the section chief. Most of the others rotated among the crew positions, particularly those positions that operated inside the trails of the howitzers. (From subsequent discussions with experienced artillery officers, what we observed was fairly typical artillery crew behavior: crew members rotate to various jobs to avoid fatigue and boredom.) In any event, after the audiometer failure we administered audiograms to up to six crew members before and after each loading and firing test condition. After the audiometer was repaired, we tested up to eight crew members, and continued this practice into Phase 2 of the test.

Elaborate statistical manipulation of the threshold shift data did not appear to be appropriate in view of the relatively small numbers of crew members involved in the tests. One of the primary concerns, from an audiometric standpoint, was whether the crew members' temporary threshold shifts (TTS) exceeded that allowed under current DRC. For that reason it was decided to compute the 95th percentile TTS for various conditions (1) and compare it with the 95th percentile TTS allowed by the CHABA DRC (2) which is the underlying basis for MIL-STD-1474A(MI). CHABA C_{95} allowable TTS is 10 dB at or below 1000 Hz, 15 dB at 2000 Hz, and 20 dB at or above 3000 Hz.

Since a preliminary inspection of the raw data indicated no systematic left-right ear differences, the ears were lumped together in the computations. Crews were also lumped together for comparable test conditions.

Data for all of the test frequencies are included. However, the data for 500 Hz are suspect and should not be used to form any strong conclusions. The main problem with the 500 Hz data is that they represent masked thresholds (see Table 2). Masking is known to have been present and resulted because of essential operation of the air conditioner during the testing. In addition, it seems possible that, because of the masking, some 500 Hz threshold shifts may have been missed and thus recorded as zero shift. Alternatively, some of the 500 Hz shifts that were observed could have resulted because 500 Hz (in the left ear) was always tested first, and threshold tracking may therefore have been less than optimal.

Table 4 presents the C_{95} values computed for the combined ears of (male) crews A, B and C for each of the seven test conditions in which these crews participated. As previously stated, the unequal n's resulted because of test scheduling and also because one of the audiometers could not be used to test 8000 Hz. Summary statistics on the TTS of crews A, B and C are included in Appendix C.

There were several instances of individual crew member's TTS equalling or exceeding the CHABA limits. A member of crew A had an earplug come loose during the 105mm loading condition #3; he demonstrated 20 dB TTS at 6000 Hz in his left ear, and 15 dB TTS at 8000 Hz in his left ear. In the third 105mm test condition, one member of crew B demonstrated a 23 dB TTS at 8000 Hz in his right ear. Since the CHABA DRC (2) permits 5 percent of the data points to exceed the stated TTS limits, these individuals' TTS fall within the allowable limits.

Table 5 presents the C_{95} values computed for the combined ears of (female) crews D and E for each of their training sessions and test conditions.

TABLE 4

C_{95} Temporary Threshold Shift (dB) for Combined Ears of the Male Crew Members

Test Condition	N	500	1000	2000	3000	4000	6000	8000	N8K*
		Test Frequency (Hz)							
105mm 60 rds #1	24	7.5	5.5	4.0	1.0	5.5	10.0	9.5	18
105mm 60 rds #2	22	3.5	3.0	4.5	5.0	5.0	12.0	10.0	16
105mm 60 rds #3	36	5.0	4.0	4.5	4.5	5.0	14.5	19.5	24
122mm 50 rds	16	15.5	7.0	8.0	9.0	8.0	8.5	10.0	12
155mm 60 rds #1	24	7.0	8.0	8.0	5.5	6.5	8.5	13.5	18
155mm 60 rds #2	28	4.0	6.0	6.0	6.0	6.0	9.0	7.5	20
155mm 60 rds #3	32	6.0	4.0	6.0	3.0	4.0	7.0	8.0	20
CHABA C_{95} Limits		10.0	10.0	15.0	20.0	20.0	20.0	20.0	

*The n for 8000 Hz was smaller because one of the four audiometers could not be used at that frequency.

TABLE 5

C_{95} Temporary Threshold Shift (dB) for Combined Ears of Female Crew Members

Test Condition	N	500	1000	2000	3000	4000	6000	8000	N8K*
		Test Frequency (Hz)							
105mm Training	26	5.0	0	3.0	4.0	4.0	6.0	8.5	20
105mm 30 rds #1	26	8.0	4.0	2.0	2.0	0	10.0	8.0	22
105mm 30 rds #1	24	6.0	3.5	5.5	0	8.0	9.0	14.0	20
105mm 45 rds #1	24	2.5	5.0	4.0	5.0	7.0	13.0	8.0	18
105mm 45 rds #2	12	15.0	9.0	4.0	8.0	12.0	15.0	8.0	8
105mm 29 rds	12	6.0	7.0	7.0	6.0	6.0	9.0	10.0	10
155mm Training	20	8.0	6.0	2.0	7.0	2.5	10.5	13.0	16
155mm 15 rds	20	4.0	5.5	2.5	9.0	3.0	13.0	10.0	14
155mm 29 rds #1	12	6.0	8.0	4.0	2.0	2.0	5.0	14.0	10
155mm 29 rds #2	20	0	3.0	0	1.0	3.5	6.5	6.0	16
155mm 30 rds	20	5.0	4.5	2.5	3.0	2.0	10.5	20.0	14
105/155 Mix	20	5.0	5.0	0	3.0	1.0	6.0	15.0	14
CHABA C_{95} Limits		10.0	10.0	15.0	20.0	20.0	20.0	20.0	

*The n for 8000 Hz was smaller because one of the four audiometers could not be used at that frequency.

There was one instance of a crew member's TTS equaling or exceeding the CHABA C_{95} values. After the 155mm, 30-round condition, one crew member showed a 20 dB TTS at 8000 Hz in her left ear. Further summary statistics on crews D and E are included in Appendix D.

Further statistical manipulation of these data did not appear to be warranted in view of the small amounts of TTS that were generally observed, in addition to the missing data points (unequal n's) resulting from differences among the four audiometers, etc.

DISCUSSION

Pre-Exposure Hearing Levels

The participants pre-exposure (i.e., baseline) hearing levels are summarized in Table 1 and Appendix A. These data suggest that, on the average, the participants in all five crews could hear about equally well. There was, of course, one man in crew A who had a Class 2 profile for hearing-his upper frequency hearing levels were quite high. There were three other men in crew A with hearing levels above 25 dB at one or more test frequencies. One man in crew B had a similar problem, and two on crew C were similarly affected. By contrast, none of the female participants had hearing levels in excess of 25 dB at any test frequency. Thus, it was not surprising to note that there was a tendency for the hearing levels of the two female crews (D and E) to be better than those of crews A, B and C. Such a difference might even have been expected, given the fact that all of the male participants were experienced artillerymen, and none of the female participants came from an artillery background (11).

Impulse Noise Characteristics

Table 3 shows the impulse noise characteristics determined for the three weapons used in the loading study. Since the monitoring gage was closer to the noise source (i.e., gun muzzle) than the crew personnel, these measured characteristics may be more severe (or at least different) than that to which the crew was actually subjected. The A-duration for the 105mm howitzer, in particular, is shorter than would have been expected. This may have been due to the atypical placement of the transducer.

Another aspect of the noise exposure which is reflected in Table 3 is the variability of the data. In much of the research underlying the CHABA DRC (2), small arms noise was used and typical standard deviations for peak pressure level range from 0.4 to 0.9 dB for different lots of ball ammunition. But the standard deviations of the howitzers' peak pressure levels ranged from 0.91 to 1.48 dB, and the inescapable conclusion seems to be that artillery noise really is much more variable than small arms noise.

Two possible contributors to the variability of the crew noise exposures may be cited. One was the low zone charges that were fired. Both the 105- and 155mm systems fired the Zone 3 charge, and the 122mm system used a two-pound charge. Crew mobility was, undoubtedly, another contributor to the variability of the actual crew noise exposure. The only way to determine actual crew noise exposure would be to instrument each crew member and record the impulse noise received during the loading and firing operations.

A final comment on the impulse noise characteristics relates to the question of using mean versus maximum data in assessing hearing damage risk from impulse noise exposure. In most of the studies (3) underlying the CHABA DRC (2), the mean peak level and B-duration were used to describe the impulse noise exposure. Recently, however, it has been suggested that maximum values should be used. (Certainly, this would be a much more conservative approach.) The effect of such a change may be illustrated by the following example from this loading study. For the 155mm howitzer, the mean recorded peak level was 172.9 dB and the mean B-duration was 34.6 msec. This combination falls just above the "Y" curve in Figure 5 of MIL-STD-1474A(MI) (5). The maximum values for the 155mm howitzer were 182.5 dB peak level and 43.6 msec B-duration. This combination falls significantly above the "Z" curve in the standard. And this was for Zone 3 charges! Using maximum rather than mean data would impose severe restrictions on the utilization of standard Army weapons.

Extent of Temporary Threshold Shift Observed

The primary purpose for monitoring the participants' hearing levels before and after each firing sequence was to avoid excessive threshold shifts. That goal of the study was achieved. The threshold shifts that were observed were generally small and recovered quickly. This was not surprising, inasmuch as most of the estimated crew exposures were far below the allowable exposure limits of MIL-STD-1474A(MI) (5). These findings are consistent with those of Pfander (9). In general, good single hearing protectors provide adequate protection.

The data for the three male artillery crews (Table 4 and Appendix C) show only two instances in which individual threshold shifts exceeded the CHABA limits. In one of those cases, the crewman had an earplug to come loose during the firing, which would certainly have had the effect of increasing that ear's noise exposure on that occasion.

For the female crews (Table 5 and Appendix D), we had originally expected to have comparable noise exposures (i.e., same number of rounds fired per test sequence) and that would have enabled a comparison of results with the males. The females, having had less overall (lifetime) noise exposure than the males, might have been more susceptible to threshold shift and demonstrated larger temporary hearing losses. However, the females only fired 45 rounds per condition as compared with 60 rounds for the males on the same weapons. As it turned out, there were only three instances in which individual female ears' threshold shifts exceeded the CHABA limits. Also, there was no apparent trend toward more or less threshold shift as the daily testing progressed.

Negative Threshold Shift

In impulse noise studies it is often found that some ears are more acute after noise exposure than before, and this phenomenon has been termed "negative threshold shift." The descriptive model of negative threshold shift developed by Hodge (6) posits a release from inhibition basis. That is, the initial effect of impulse noise exposure is to reduce the known inhibitory effect of the receptor cells which allows adjacent receptors to exhibit an apparent increase in sensitivity. Viewed this way, negative threshold shift is a detrimental effect of noise exposure; an effect lying somewhere between no effect (i.e., zero threshold shift) and a positive threshold shift or measured loss of sensitivity.

Negative threshold shift exerts an effect on the statistical interpretation of threshold shift data. Traditionally, threshold shift values have been arranged in rank order (sign included) and percentile values computed on the data so ranked. This approach was used in most of the experiments (3) leading up to the CHABA DRC (2). But, if we were to treat negative shift as the precursor of a loss process, it probably would be more appropriate to arrange all the threshold shift data in order by absolute value (sign ignored). The effect of this approach is illustrated in Table 6 which lists various percentile values for the data of male test condition "105mm, 60 round, number 3" (chosen only for its large number of cases). The "signed" values were computed in the conventional manner whereas the "absolute" values were computed ignoring sign. The effect is most pronounced for the 75th and 95th percentiles.

SUMMARY

A test was conducted to determine artillery loading and firing rates for three artillery systems (105-, 122- and 155mm howitzers), using both male and female crews. Audiometric and acoustical support were provided with these overall objectives: (a) estimate the crews' impulse noise exposure, (b) insure that excessive hearing losses would not occur, (c) compare temporary threshold shifts with that permitted under current hearing damage risk criteria, and (d) look for any trends in the results of the near-daily weapon firing.

TABLE 6

Comparing Statistics for Signed Versus Absolute Values of Threshold Shift
(Male Crews, 105-60 #3)

		Test Frequency (Hz)						
		500	1000	2000	3000	4000	6000	8000
C_{50}	Signed	0	0	0	0	0	0	2.0
	Absolute	0	0	0	1.0	0	3.5	7.0
C_{75}	Signed	0	0	1.0	3.0	0	2.5	8.5
	Absolute	2.0	1.0	3.0	3.5	4.0	8.0	10.5
C_{95}	Signed	5.0	4.0	4.5	4.5	5.0	14.5	19.5
	Absolute	6.0	4.5	5.5	5.0	7.5	17.5	19.5
	n	36	36	36	36	36	36	24

The impulse noise characteristics of the three weapons used in the test were quite variable. Contributing factors may have been the remote location of the measuring transducer and/or the low zone charges that were fired. Crew member mobility within and between test conditions also contributes to the variability of the actual impulse noise exposure.

There were no instances of excessive threshold shift, and no crew members had to be withdrawn from the test because of noise-induced auditory problems. Since only one of the test conditions (122mm howitzer for male crews) approached the exposure limits of MIL-STD-1474A(MI), it was not surprising that there were few instances of threshold shifts approaching the allowable limits. In general, the threshold shifts were small and recovered quickly. There were no trends toward either an increase or decrease in the threshold shifts across the sequence of test conditions.

RECOMMENDATIONS ABOUT FUTURE TEST SUPPORT

Discussions have already been conducted regarding additional, intensive weapon operations exercises for which audiometric and/or acoustical support might be provided. Based on the experiences we had in the present field study it seems appropriate to make some general recommendations about supporting future exercises.

First, there should be a good reason for investing the manpower and funds in such support. In the audiometric testing area, there should be a reasonable expectation that the gun crew noise exposure will approach current exposure limits, otherwise such an effort is a waste of time. Current medical regulations do not require daily hearing tests for personnel undergoing artillery training, nor participating in readiness exercises and proficiency tests. (Medical and safety requirements are satisfied if all crew personnel wear hearing protective devices.) So, we should not have to give audiograms to people just because they are in a loading test.

One acoustical measurement objective that might be achieved in a future firing test is determining the actual crew member noise exposure. This seems not to have been done before for gunfire noise exposure, and would entail developing a wearable noise recording system. Among the technical problems that would have to be solved are deciding what type of transducer to use and where to mount it.

Significant improvements in instrumentation within this Laboratory are needed. It should be possible to obtain both real time and recorded impulse noise data for every shot. The audiometric testing should be conducted in a temperate enclosure with the air handling system in operation. And, all of the audiometers used should provide the same HTL range.

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APPENDIX A

INDIVIDUAL BASELINE HEARING LEVELS

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TABLE 1A

Individual Pre-Exposure Baseline Hearing Levels of the Male Test Participants
(dB re ANSI-1969 Zero)

		LEFT EAR							RIGHT EAR						
		500	1000	2000	3000	4000	6000	8000	500	1000	2000	3000	4000	6000	8000
A	1	11	3	0	0	0	8	3	8	3	1	0	0	0	3
	2	18	7	0	0	4	12	3	8	0	-2	7	2	4	6
	3	10	4	1	0	5	10	27	5	-5	-2	-3	-2	10	6
	4	16	16	19	9	19	17	30	11	12	10	22	17	14	29
	5	5	5	9	-2	-5	-4	-12	5	5	5	3	2	1	-11
	6	14	2	0	2	28	64[a]	56[a]	16	7	0	-2	5	53[a]	45[a]
	7	5	5	2	1	-5	-9	0	7	2	0	0	-4	-10	-11
	8[b]	13	12	13	59[a]	70	75[a]	--[c]	16	13	9	37	30	62[a]	--[c]
	9	3	3	-2	0	2	4	7	2	1	-8	-2	4	2	7
B	1	5	0	-8	0	2	0	-15	0	-10	-15	-2	0	0	0
	2	5	2	14	14	12	15	13	7	7	17	16	11	17	14
	3	13	10	0	-2	8	16	23	7	3	3	-2	6	12	-2
	4	13	13	13	4	9	13	14	11	16	10	3	6	13	-2
	5	5	0	3	0	2	16	0	0	-5	-8	-15	-8	5	9
	6	15	0	5	6	19	19	-2	13	5	-5	3	10	3	-2
	7	4	0	13	5	0	0	2	2	0	10	5	3	-5	2
	8	7	3	7	7	12	11	18	3	-3	-3	15	14	55[a]	56[a]
	9	8	-1	1	8	14	14	20	3	-3	-3	15	14	55[a]	56[a]
C	1	10	0	0	0	0	7	0	7	4	-6	3	4	-4	0
	2	15	12	14	10	7	7	3	10	11	11	8	-3	8	5
	3	12	7	2	2	2	7	11	10	0	-2	-1	2	7	9
	4[d]	11	9	15	75[a]	90	76[a]	--[c]	8	9	23	75[a]	82	65[a]	--[c]
	5	14	20	23	7	32	12	9	9	10	20	6	15	13	18
	6	13	5	3	0	12	8	15	11	6	3	9	11	15	10
	7	12	12	7	4	7	8	-2	15	8	2	5	3	7	-2
	8	8	0	0	0	13	0	9	1	0	-5	0	-3	-5	3
	9	8	3	5	10	21	18	1	0	1	3	-5	5	9	7

[a]These values not used in assigning hearing profile class under present version of AR 40-501.
[b]This man had a Class H2 profile.
[c]This frequency not tested with this person.
[d]This man had a Class H1 profile despite his pronounced bilateral hearing losses.

TABLE 2A

Individual Pre-Exposure Baseline Hearing Levels of the Female Test Participants
(dB re ANSI-1969 Zero)

		LEFT EAR							RIGHT EAR						
		500	1000	2000	3000	4000	6000	8000	500	1000	2000	3000	4000	6000	8000
D	1	10	3	4	13	5	8	2	6	4	0	7	1	3	1
	2	7	0	7	2	3	4	1	6	1	0	6	1	17	25
	3	-3	-3	-4	6	11	10	9	-3	-5	-2	-1	1	1	5
	4	10	-3	-2	-3	1	3	12	1	-6	-2	2	-4	1	21
	5	8	6	1	6	5	16	5	6	1	-1	1	8	8	2
	6	4	1	-5	2	10	-2	-3	3	-2	-3	0	8	-8	-2
E	1	5	2	-2	5	5	-2	-1	-1	-3	-4	0	-4	-7	-5
	2	2	-3	-3	-4	-1	-1	2	0	4	0	-1	-2	1	5
	3	17	10	13	1	2	10	9	11	7	11	0	1	9	8
	4	2	-4	-1	8	6	7	9	2	-1	3	10	10	10	0
	5	12	2	2	2	5	9	7	3	7	2	1	6	7	6
	6	5	5	2	-3	-3	5	6	3	8	7	-2	-3	4	1
	7	4	1	1	-4	2	-2	1	2	2	2	-5	-1	-8	-6

APPENDIX B

ARTILLERY WEAPONS AND IMPULSE NOISE MEASUREMENT LOCATIONS

Figure 1B. 105mm howitzer. Measurement location (arrow) 66 inches above ground, 17 inches right of center line, 12 inches (diagonally) behind blast shield.

Figure 2B. 155mm howitzer. Measurement location (arrow) 68 inches from ground, 24 inches right of center line, 9 inches from trunion.

Figure 3B. 122mm Soviet howitzer. Measurement location (arrow) 65 inches above ground, 20 inches right of center line, 17 inches behind shield.

APPENDIX C

SUMMARY OF TEMPORARY THRESHOLD SHIFTS (dB) FOR COMBINED EARS OF MALE CREWS

Summary of Temporary Threshold Shifts (dB) for Combined Ears of Male Crews

	Test Frequency (Hz)						
	500	1000	2000	3000	4000	6000	8000
105 mm, 60 round, No. 1							
C_{50}	0	0	0	0	0	0	0
C_{75}	3.0	0	0	0	0	4.5	0
C_{95}	7.5	5.5	4.0	1.0	5.5	10.0	9.5
C_{100}	8.0	6.0	4.0	2.0	8.0	10.0	12.0
n	24	24	24	24	24	24	18
105 mm, 60 round, No. 2							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	0	0	2.0	0	4.0	5.0
C_{95}	3.5	3.0	4.5	5.0	5.0	12.0	10.0
C_{100}	4.0	4.0	5.0	5.0	5.0	12.0	10.0
n	22	22	22	22	22	22	16
105 mm, 60 round, No. 3							
C_{50}	0	0	0	0	0	0	2.0
C_{75}	0	0	1.0	3.0	0	2.5	8.5
C_{95}	5.0	4.0	4.5	4.5	5.0	14.5	19.5
C_{100}	6.0	5.0	5.0	5.0	7.0	20.0	23.0
n	36	36	36	36	36	36	24
122 mm, 50 round test							
C_{50}	0	0	0	0	0	0	0
C_{75}	3.5	2.0	0	0	0	4.5	6.5
C_{95}	15.5	7.0	8.0	9.0	8.0	8.5	10.0
C_{100}	20.0	10.0	10.0	14.0	12.0	10.0	10.0
n	16	16	16	16	16	16	12

(Continued)

Summary of Temporary Threshold Shifts (dB) for Combined Ears of Male Crews (Continued)

	Test Frequency (Hz)						
	500	1000	2000	3000	4000	6000	8000
<u>155 mm, 60 round, No. 1</u>							
C_{50}	0	0	0	0	0	0	-3.5
C_{75}	1.0	0	0	0	0	4.5	0
C_{95}	7.0	8.0	8.0	5.5	6.5	8.5	13.5
C_{100}	8.0	9.0	10.0	8.0	8.0	10.0	17.0
n	24	24	24	24	24	24	18
<u>155 mm, 60 round, No. 2</u>							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	3.0	0	0	0	0	0
C_{95}	4.0	6.0	6.0	6.0	6.0	9.0	7.5
C_{100}	4.0	6.0	7.0	6.0	7.0	15.0	8.0
n	28	28	28	28	28	28	20
<u>155 mm, 60 round, No. 3</u>							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	1.0	1.0	0	0	3.0	0
C_{95}	6.0	4.0	6.0	3.0	4.0	7.0	8.0
C_{100}	6.0	4.0	6.0	4.0	7.0	14.0	10.0
n	32	32	32	32	32	32	20

(Concluded)

APPENDIX D

SUMMARY OF TEMPORARY THRESHOLD SHIFTS (dB) FOR COMBINED EARS OF FEMALE CREWS

Summary of Temporary Threshold Shifts (dB) for Combined Ears of Female Crews

TEST FREQUENCY (Hz)

	500	1000	2000	3000	4000	6000	8000
105 MM TRAINING							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	0	0	0	0	0	1.0
C_{95}	5.0	0	3.0	4.0	4.0	6.0	8.5
C_{100}	7.0	0	6.0	6.0	6.0	13.0	10.0
N	26	26	26	26	26	26	20
105 MM, 30 ROUND, TEST NUMBER 1							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	0	0	0	0	0	0
C_{95}	8.0	4.0	2.0	2.0	0	10.0	8.0
C_{100}	9.0	4.0	5.0	4.0	4.0	10.0	8.0
N	26	26	26	26	26	26	22
105 MM, 30 ROUND, TEST NUMBER 2							
C_{50}	0	0	0	0	0	0	0
C_{75}	1.0	0	0	0	0	0	0
C_{95}	6.0	3.5	5.5	0	8.0	9.0	14.0
C_{100}	7.0	4.0	7.0	0	10.0	12.0	16.0
N	24	24	24	24	24	24	20

(Continued)

Summary of Temporary Threshold Shifts (dB) for Combined Ears of Female Crews (Continued)

	TEST FREQUENCY (Hz)						
	500	1000	2000	3000	4000	6000	8000
105 MM, 45 ROUND, TEST NUMBER 1							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	0	0	0	0	0	3.0
C_{95}	2.5	5.0	4.0	5.0	7.0	13.0	8.0
C_{100}	5.0	8.0	6.0	5.0	8.0	14.0	9.0
N	24	24	24	24	24	24	18
105 MM, 45 ROUND, TEST NUMBER 2							
C_{50}	0	0	0	0	0	0	0
C_{75}	4.0	0	0	0	4,5	7.0	6.5
C_{95}	15.0	9.0	4.0	8.0	12.0	15.0	8.0
C_{100}	15.0	9.0	4.0	8.0	12.0	15.0	8.0
N	12	12	12	12	12	12	8
105 MM, 29 ROUNDS (RAN OUT OF AMMUNITION)							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	3.0	0	0	0	2.0	2.0
C_{95}	6.0	7.0	7.0	6.0	6.0	9.0	10.0
C_{100}	6.0	7.0	7.0	6.0	6.0	9.0	10.0
N	12	12	12	12	12	12	10

(Continued)

Summary of Temporary Threshold Shifts (dB) for Combined Ears of Female Crews (Continued)

	TEST FREQUENCY (Hz)						
	500	1000	2000	3000	4000	6000	8000
155 MM TRAINING (35 ROUNDS)							
C_{50}	0	0	0	0	0	0	0
C_{75}	3.0	1.0	0	0	0	0	4.5
C_{95}	8.0	6.0	2.0	7.0	2.5	10.5	13.0
C_{100}	10.0	6.0	4.0	8.0	3.0	15.0	15.0
N	20	20	20	20	20	20	16
155 MM, 15 ROUND, TEST							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	0	0	0	0	0	2.0
C_{95}	4.0	2.0	2.5	9.0	3.0	13.0	10.0
C_{100}	6.0	2.0	5.0	10.0	4.0	14.0	10.0
N	20	20	20	20	20	20	14
155 MM, 29 ROUND, TEST #1							
C_{50}	0	0	0	0	0	0	0
C_{75}	3.5	1.0	0	0	0	2.0	8.0
C_{95}	6.0	8.0	4.0	2.0	2.0	5.0	14.0
C_{100}	6.0	8.0	4.0	2.0	2.0	5.0	14.0
N	12	12	12	12	12	12	10

(Continued)

Summary of Temporary Threshold Shifts (dB) for Combined Ears of Female Crews (Continued)

	TEST FREQUENCY (Hz)						
	500	1000	2000	3000	4000	6000	8000
155 MM, 29 ROUND TEST #2							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	0	0	0	0	0	0
C_{95}	0	3.0	0	1.0	3.5	6.5	6.0
C_{100}	0	4.0	0	2.0	5.0	7.0	10.0
N	20	20	20	20	20	20	16
155 MM, 30 ROUND TEST							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	0	0	0	0	7.0	7.0
C_{95}	5.0	4.5	2.5	3.0	2.0	10.5	20.0
C_{100}	6.0	7.0	5.0	4.0	2.0	11.0	20.0
N	20	20	20	20	20	20	14
FINAL 105/155 MM MIX TO DISPOSE OF LEFTOVER AMMUNITION							
C_{50}	0	0	0	0	0	0	0
C_{75}	0	0	0	0	0	0	2.0
C_{95}	5.0	5.0	0	3.0	1.0	6.0	15.0
C_{100}	6.0	6.0	0	6.0	2.0	9.0	15.0
N	20	20	20	20	20	20	14

(Concluded)